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(בעברית) (Hebrew) שנאי תלת פזי ושיטה ליצורו

(באנגלית) (English) Three-phase transformer and method for manufacturing same

מבקש בזאת כי ינתן לי עליה פטנט
hereby apply for a patent to be granted to me in respect thereof.

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שנאי תלת פזי ושיטה ליצורו

Three-phase transformer and method for manufacturing same

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שנאי תלת פזי ושיטה ליצורו

Three-phase transformer and method for manufacturing same

TECHNICAL FIELD

This invention relates to three-phase electrical transformers and methods for manufacturing same, and more particularly to such transformers which include a spatial magnetic core made of amorphous alloys.

BACKGROUND OF THE INVENTION

Transformers contain two or more electrical circuits, comprising primary and secondary windings made each of a multi-turn coil of electrical conductors, with one or more magnetic cores coupling the coils by transferring a magnetic flux therebetween.

At present, a three-phase transformer structure usually includes E+I magnetic cores in a flat structure. The transformer includes several interconnected magnetic cores, located in one plane.

Transformers of this type having a magnetic core made of an amorphous metal are known in the art, as disclosed for example in US Patent No. 4,893,400 and US Patent No. 5,398,402 . These patents disclose a transformer wherein the magnetic core is made of an amorphous metal strip wound into a core over a mandrel, with one leg of the resulting core being subsequently cut off and with forming the metal into a rectangular shape. A piece of rectangular steel is wrapped around the outer periphery of the amorphous metal core.
The amorphous metal is then annealed, and the core is encapsulated in a resinous coating, except the cut leg. This allows the opening of the cut leg.

The layers of amorphous alloy strips of the two edges are oriented so that the edges define top and bottom surfaces, each surface having a discontinuity defining a distributed gap portion extending from the top surface to the bottom surface. The coils are placed over the two long legs and the cut leg is closed. The joint is then sealed.

In US Patent No. 4,893,400 , the sealing is made with glass cloth and an ultraviolet-curable resin to provide the structure by the "fit and cure" method. This method is costly and labor-intensive. The transformer having

amorphous metal cores manufactured according to the above-detailed method cannot be repaired without causing damage to the core.

In US Patent No. 5,398,402 , the sealing is made with a porous material such as woven cotton cloth or paper. The porous material is folded over the joint and secured into position. An additional piece of porous material is placed through the window of the core, is wrapped around the core and is secured there. An electrical grade steel is disposed around the transformer core and is closed around the core joint and tack-welded. This structure allows the cut leg to be opened to permit replacement of a defective coil, however the operation is time-consuming and labor-intensive.

In US Patent No. 5,441,783 , the coating used to impregnate the core joint is a porous material with a viscosity greater than about 100,000 cps and a bonding material with a viscosity of at least about 100,000 cps. The porous material comprises strands of fiber and the bonding material is a thixotropic epoxy. The coated cores have good magnetic properties, but the method of their manufacture is costly and complex. The method of repairing these cores is labor-intensive.

Another disadvantage of transformers made according to the above-mentioned patents is that annealed amorphous metals become extremely brittle, and thus break under mechanical stress, for example during the stage of closing the core joint.

Whereas the above-mentioned patents disclose a planar core structure, US Patent No. 4,639,705 discloses a structure having a spatial magnetic core system. This structure has advantages over the planar "E+I" structure, for example:

1. The quantity of required magnetic materials is reduced by about 20-30%
2. The transformer has a reduced volume
3. Core losses are reduced by about 20-30%
4. The currents in the three phases of the primary windings are balanced

A transformer manufactured according to US Patent No. 4,639,705 , however, requires a complex production technology as well as a complex repair technology.

It is an objective of the present invention to address the problems of transformer manufacture and maintenance.

SUMMARY OF THE INVENTION

According to the present invention, a novel transformer structure is used to achieve three-phase transformers having higher efficiency and smaller magnetic core, that use lower quantities of materials per unit electrical power and/or have better maintainability.

According to one aspect of the present invention, the transformer has a symmetrical tri-dimensional structure using core elements made of wound ribbons of a soft ferromagnetic amorphous alloy. The three columns each corresponding to one phase magnetic core, as well as the top and bottom parts, are made of these core elements.

According to another aspect of the invention, the top and bottom pieces of the transformer are made each of an amorphous ribbon wound into a generally triangular shape with rounded corners to effectively transfer magnetic flux between the three magnetic core columns.

According to a third aspect of the invention, each magnetic core column may comprise a plurality of core elements stacked one on top the other, to achieve a magnetic core column of increased height, although the width of each amorphous ribbon is limited. The stacked structure column achieves good conductivity of the magnetic flux (low reluctance) along the column, while presenting a high impedance to eddy currents.

According to a fourth aspect of the invention, the transformer magnetic core is easy to assemble and dismantle, to allow easy manufacture and maintenance. Structural means in the transformer reliably secure the transformer parts in place during its operation, while allowing for dismantling the transformer for repairs.

The magnetic core may include a radial slot, to further reduce eddy currents and to prevent the induction of a high voltage in the core, which may otherwise cause a breakdown of the isolation between the core windings.

Other core structures are disclosed, including ribbon pieces attached to each other, with each ribbon piece being in a planar state and oriented along the magnetic core.

The present disclosure further teaches of a suitable proportion between the diameter of each magnetic core and the upper and lower parts, to achieve the desired transformer properties while using less raw material.

Further objects, advantages and other features of the present invention will become obvious to those skilled in the art upon reading the disclosure set forth hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates schematically the structure of the three-phase transformer.

Fig. 2 illustrates a perspective view of the three-phase transformer.

Fig. 3 is a cross-sectional view, along lines AA in Fig. 2, of the three-phase transformer.

Fig. 4 details one column of the three-phase transformer and means for its attachment.

Fig. 5 details one column of the three-phase transformer and another embodiment of means for its attachment.

Fig. 6 details a method of manufacture of the base plate 2 of the magnetic core.

Fig. 7 details the structure of one column of the three-phase transformer, comprising a plurality of toroids.

Fig. 8 details the structure of one column of the three-phase transformer, including longitudinally-oriented ribbon parts.

Fig. 9 details the structure of one column of the three-phase transformer, after mounting the secondary winding on the magnetic core.

Fig. 10 details the structure of one column of the three-phase transformer, after mounting the primary winding on the magnetic core.

DETAILED DESCRIPTION OF THE INVENTION

A preferred embodiment of the present invention will now be described by way of example and with reference to the accompanying drawings. Fig. 1 illustrates schematically the structure of the three-phase transformer.

Operation of the transformer: The magnetic core of the transformer comprises an upper plate 1, a lower plate 2 and three identical columns 3. The magnetic core is mounted so that plates 1 and 2 are parallel to each other, with columns 3 mounted as supports between the plates so as to form a cage-like structure having a spatial symmetry about a central axis.
Each of the coil blocks 4 is mounted over one of the columns 3. Each of the coil blocks 4 includes (not shown) a primary and a secondary winding for one of the three phases of the transformer.

As current passes through each primary winding of coil block 4, a corresponding magnetic flux is generated, with that flux propagating along column 3 between the upper plate 1 and lower plate 2. The flux generated in each column 3 is indicated with flux arrows 81, 82 and 83.

The magnetic flux flowing through each of the columns 3 generates in turn an induced voltage in the secondary winding of the corresponding coil block 4. The device with the abovedetailed structure thus functions as a three-phase transformer.

The problem is now to provide for a return path for the magnetic flux. That is, magnetic flux 81, 82 and 83 flowing through the three columns 3 from plate 2 to plate 1 has to return somehow back to plate 2, to close the loop for that flux. A solution used in the art is to provide a return path for the flux of each phase, for example by using for each phase a closed magnetic loop. The common magnetic path adds to the size and weight of the transformer.

In the structure according to the present invention, the return path is eliminated altogether. The rational is that the magnetic flux 81, 82 and 83 streams form the three phases of an alternating, sinusoidal field. Thus, the magnetic flux streams 81, 82 and 83 in columns 3 have an equal magnitude and a 120 degrees phase difference therebetween. Therefore, the phasor sum of the three magnetic flux streams is zero, and there is no need for a return magnetic path between plates 1 and 2.

This structure saves the material for the return path, allowing a smaller transformer of less weight.

The above structure is useful for balanced three-phase systems (the currents have equal amplitude and a 120 degree phase difference). The transformer will also perform well when there is a small imbalance between the three phases in terms of relative amplitude or phase. Where a significant imbalance is to be expected, a transformer with a magnetic flux return path should be preferably used. This may be implemented with a (not shown) fourth magnetic core column spanning the distance between plates 1 and 2, and in parallel with columns 3. Still, the residual flux (the result of the imbalance) is expected to be smaller than the flux in each phase, thus the fourth magnetic core column may be made thinner (having a smaller diameter or cross-sectional area) than columns 3.

Thus, even in an extreme case where severe imbalance is expected, the magnetic core is smaller and consumes less material to manufacture than a transformer of the same rated power, having a structure as known in the art.
A fourth magnetic core column may be placed, for example, between the center of plate 1 and the corresponding center of plate 2.

Mechanical structure: The transformer has a modular structure – plates 1 and 2 and columns 3 can be mounted together or taken apart. When one of the plates 1 or 2 is removed, coil blocks 4 can be removed as well, to repair a coil for example. To secure all the parts of the transformer together, three screws (not shown) may be used for example, with each screw passing through a central hole 32 in column 3, a hole 10 in plate 1 and a corresponding hole in plate 2. A nut (not shown) mounted on each screw may be used to attach together parts 1, 2 and 3.
This achieves a robust and reliable structure, yet a structure that may be easily dismantled.

Structure of magnetic core: The plates 1 and 2 are identical, thus the following description that refers to the structure of plate 1 may be applied to plate 2 as well.
Plate 1 of the magnetic core is a toroid. The plate 1 is made of an amorphous ribbon 17 that is wound about a central hole 15 to form a planar toroid as illustrated. The plate 1 may be circular.

In a preferred embodiment, plates 1 and 2 have a generally triangular shape with rounded sides and corners, as illustrated in Fig. 1 and as detailed below. After forming the plate 1 of the desired shape and size, the excess ribbon 17 is cut off. The amorphous ribbon 17 is made of an alloy having soft ferromagnetic properties, as required of a magnetic core for a transformer. Amorphous ribbons are known to have good ferromagnetic properties. The structure of the transformer according to the present invention allows to benefit from these properties in a practical transformer structure.

Each of the columns 3 is also a toroid, or a plurality of toroids stacked on top of each other. In the embodiment as illustrated, each column 3 comprises three toroids 33, 34 and 35. This solves the problem of achieving a column 3 of a desired height, while the width of practical amorphous ribbons is limited. According to the present invention, a transformer with any desired height of columns 3 can be achieved by stacking toroids of limited height on top each other as illustrated.

All the parts 1, 2 and 3 of the magnetic core as illustrated in Fig. 1 comprise amorphous ribbons wound about a vertical axis. The relative orientation of the parts 1, 2 and 3 allow for good magnetic flux transfer, so that a magnetic circuit having low reluctance is achieved. Thus, magnetic flux streams 81, 82 and 83 pass easily along columns 3, flowing from one flat side of each toroid (33, 34 or 35) to the other flat side of the toroid. In plates 1 and 2, segments of ribbon between any two adjacent columns 3 provide good ferromagnetic paths for the magnetic flux.

For instance, assuming that at a given moment flux 81 equals and balances the sum of flux streams 82 and 83, and flux 81 flowing down, then in plate 1 the flux streams 84 and 85 transfer flux streams 82 and 83 respectively to the column carrying back the flux stream 81. In plate 2, flux 81 is divided into flux streams 86 and 87 that flow back to columns 3 to form flux streams 82 and 83 respectively. Thus the magnetic flux loop is closed.

In an embodiment wherein plates 1 and 2 have a circular form, the flux streams 84, 85, 86 and 87 flow along circular paths therein. In a preferred embodiment as illustrated, plates 1 and 2 have a shape that is close to a equilateral triangle with rounded sides and corners.
This results in a shorter path for flux streams in plates 1 and 2 between columns 3, that is the shape of the flux streams is closer to a straight line. This achieves lower magnetic reluctance, or better conductance of the magnetic flux. A more efficient structure is achieved, using less raw material for the magnetic core.

Each winding in coil block 4 is made of copper wire (not shown). Each coil may have a winding and case insulation compatible with the working voltage and the cooling system used. If air cooling is used, a relatively thick insulation may be required. In case the transformer is immersed in oil, a thinner insulation may be used for the same voltage. The oil may be used for cooling as well as for insulation between the windings.

Transformer design: The cross-sectional area of columns 3 and the corresponding area in plates 1 and 2 is set according to the power rating of the transformer and the ferromagnetic property of the amorphous alloy these parts are made of. The height of each column 3 and the distance between the columns is derived from the dimensions of the coil blocks 4, according to the cross-sectional area of the wires, the number of turns and the required isolation. The dimensions of plates 1 and 2 are such as to form a base for the whole cross-sectional area of all the columns 3, when the columns 3 are located at the required distance therebetween. This allows the magnetic flux from columns 3 to pass to plates 1 and 2.

In one embodiment of the invention, the toroids 1, 2, 33, 34 and 35 were each made of an amorphous ribbon of about 20 mm (millimeter) width and 25 micron thickness.
Toroids 33, 34 and 35 may be made from ribbons in the range about 10 to 100 mm wide, or as is possible with the ribbon manufacturing process.

Transformer assembly: The various parts of the transformer may be separately and concurrently produced, then assembled together in the final step.

The preparation method may include the following stages:

1. Production of amorphous ribbons of an alloy having soft ferromagnetic properties.

2. Production of magnetic core elements (toroids) 1, 2, 33, 34, and 35. Each column 3 may comprise one or several toroids, according to total required height of column 3 and the width of each toroid.

3. Assembly of three columns 3 from toroids, in case column 3 includes several toroids.

4. Production of coil block 4 assemblies, with each block including a primary and secondary winding. Alternately, each winding may be separately produced and assembled as a separate unit.

5. Impregnation and/or coating of the core elements and/or windings.

6. Assembly of the transformer: Insert a core 3 into each coil block 4 and secure coils in position. Mount three columns 3 each in a corner of the base triangle of part 2, and place part 1 on the three columns 3. Secure all the parts 1, 2, 3 together using screws or tension bands or similar mechanical means.

Preparation of the amorphous ribbon toroids : At present, to obtain good magnetic properties, the as-cast amorphous ribbons are annealed at a temperature of about 350 to 550 degrees Celsius. The disadvantage of this prior art method is that amorphous ribbons become extremely brittle after annealing, usually breaking under mechanical stress or during winding of a toroid. To overcome this deficiency, the following method is used according to the present invention:

1. Coating an as-cast amorphous alloy ribbon with an insulating layer. The thickness of the two-sided insulation need be no more than about 5 micron. For a low-voltage transformer, this stage may be omitted.

2. Winding of a toroid (like toroids 1, 2, 34) from the as-cast ribbon. The winding is made using a steel mandrel (not shown). For parts 1 and 2 the cross-sectional area of the mandrel is triangular, as detailed below with reference to Fig. 6 , and the mandrel thickness is preferably about the same dimension as the width of the ribbon to be wound. The mandrel should have rounded corners to prevent cracks in the amorphous ribbon, for example corners with a radius about 10 mm .

For toroids 33, 34 and 35, the mandrel has a cylindrical shape. The mandrel diameter depends on the dimensions of the toroids to manufacture and may be in the range of about 10 to 30 mm .

The mechanical tension in the ribbon is set according to the required winding density coefficient, which usually is about 0.8 to 0.9 .

To force the layers of the toroid to be laid exactly on top each other, the mandrel may have (not shown) cheeks or delimiters mounted thereon. Using this method, the variation in toroid width may be limited to a small value, for example about +- 0.2 mm .

3. The last layer of the toroid is secured to the previous layer to prevent the toroid from unfolding. This may be achieved, for example, using resistance welding.

4. Annealing of the complete toroid at a temperature of about 350 to 550 degrees Celsius, preferably in a furnace with a controlled atmosphere, for a time period of less than one hour. The toroid may be annealed with the mandrel still inserted therein. Annealing may be performed with or without an external magnetic field being applied to the toroid. A longitudinal or transverse magnetic field may be applied.

5. Impregnation of the toroid with an organic binding material, for example an epoxy resin in a vacuum chamber or in an ultrasonic bath. After impregnation, the toroid is placed in a temperature-controlled environment. Impregnation may be performed with the mandrel still in the toroid.

6. The mandrel is removed from toroid. Excess impregnation material is removed from the planar surfaces of the toroid, or at least one surface for parts 1 and 2. The working surfaces (areas used to transfer magnetic flux) may be polished to achieve planar surfaces for good flux transfer and low magnetic resistance. The ends of the toroid may be made parallel to within 0.2 mm .
In another implementation of the invention, polishing is performed before step 4 (annealing), while the toroid already has a fixed shape and the amorphous ribbon is not yet brittle, thus more workable.

For toroids 33, 34 and 35, a radial slot may be cut in the toroid, as illustrated with slot 37 in Fig. 7 . Slot 37 may be made with (not shown) a corundum disk of a 200 mm diameter and 0.5 to 1 mm thickness for example, using a cooling liquid and with the toroid secured in a suitable fixture.
Slot 37 is preferably filled with an insulator material, for example a glass-cloth-base laminate.

7. To achieve better mechanical strength, the lateral circular area of the toroid is coated with a glass-cloth-base laminate band that is wound about the toroid. After coating, the band is sintered at a temperature of about 100 to 130 degrees Celsius .

Fig. 2 illustrates a perspective view of an assembled three-phase transformer. The magnetic core includes the upper plate 1, the lower plate 2 and three columns 3. The whole structure has a spatial symmetry about a

central axis 13. Each phase of the transformer includes a core 3 with a coil block 4 mounted thereon. Block 4 includes a primary winding 41 and a secondary winding 42. The whole structure is held together with three demountable bands 51, each having a screw 52 to tighten each band. Structural member 53 located between band 51 and each of the plates 1 and 2. The transformer also includes a base support 54.

The flux in each column 3 is indicated with flux arrows 81, 82.
The inner (upper) surface 26 of plate 2 comes in contact with the lower surface of columns 3, to transfer the magnetic flux therebetween.

Fig. 3 is a cross-sectional view, along lines A–A in Fig. 2, of the three-phase transformer. It details the lower plate 2, the three columns 3 of the magnetic core each having a central hole 32 therein, with the columns 3 arranged symmetrically about the central axis 13.
A coil block 4 is mounted on each column 3, with that block 4 including a primary winding 41 and a secondary winding 42.

The structure is held together with the three demountable bands 51, each with a structural member 53 located between band 51 and plate 2.
The transformer parts may be secured together using a screw band as shown, or a spider.

Plate 2 preferably has a protective coating 29 for prolonged life.

Fig. 4 details one column of the three-phase transformer and means for its attachment. The column includes the column 3 of the magnetic core, mounted between the upper plate 1 and the lower plate 2. The primary winding 41 of the coil block and the secondary winding 42 are mounted on column 3.
The structure is held together with demountable bands 51 which are tightened with screws 52. A structural member 53 is located between band 51 and each of the plates 1 and 2.
The type and size of the attaching means 51, 52 and 53 may depend on the dimensions and rated power of the transformer.

As the inner (upper) surface 26 of plate 2 comes in contact with the lower surface 37 of columns 3, to transfer magnetic flux in the transformer, a narrow gap 62 may be generated therebetween. The width of gap 62 may be about 0.2 mm for example. This gap 62 should preferably be filled with a magnetic paste, to improve the overall ferromagnetic property of the magnetic loop, that is to decrease the magnetic resistance.

The magnetic paste may include amorphous powder with soft ferromagnetic properties, having particle size larger than about 20 micron, and a binding insulating material like transformer oil or epoxy resin. The concentration of amorphous powder in the paste is usually between 50% and 90% .

Other means as known in the art may be used to minimize gap 61 and its influence on the magnetic loop.
The outer (lower) surface 27 of plate 2 may have protective coating applied thereon.

Similarly, there may be a narrow gap 61 between surfaces 16 (of part 1) and 36 (of column 3) at the upper part of column 3. Gap 61 should be filled with magnetic paste.
The outer (upper) surface 18 of plate 1 should preferably have a protective coating applied thereon.

Fig. 5 details one column of the three-phase transformer including another embodiment of means for its attachment.
The upper plate 1 and lower plate 2, together with column 3 of the magnetic core, are held together with a threaded beam or screw 54.
The structural members 53, that are attached to each of the plates 1 and 2, includes means adapted for the thread and nut structure.

The primary winding 41 of the coil block and the secondary winding 42 are mounted on column 3.
A narrow gap 62 may be formed between parts 2 and 3, that is between the inner (upper) surface of plate 2 and the lower surface of columns 3.
Similarly, gap 61 may be formed between parts 1 and 3.
It is advisable to fill gaps 61 and 62 with magnetic paste or similar means.

Fig. 6 details a method of manufacture of the base plate 2 of the magnetic core.
A mandrel 7 having a triangular cross-section and rotating about axis 71 as shown may be used.
An amorphous ribbon 17 is secured to mandrel 7 , which is then rotated as indicated with arrow 72. When the desired size for plate 2 is achieved, the plate is fixed in that state using impregnation or welding, and excess ribbon 17 is cut off.

Because of the triangular cross-section of mandrel 7, plate 2 has a generally equilateral triangle shape with rounded corners and sides. This

specific shape has advantageous properties for the three-phase transformer, as detailed elsewhere in the present disclosure.

Fig. 7 details the structure of one column 3 of the three-phase transformer, comprising a plurality of toroids 33, 34 and 35. All the toroids 33, 34 and 35 have a central hole 32 therein. The whole column 3 has an outer cover 36, preferably of an insulating material, to prevent induction of current therein because of the alternative magnetic flux in the core. The cover 36 may be made, for example, from a glass-cloth laminate impregnated with an epoxy resin.

The toroids 33, 34 and 35 are made of an amorphous ribbon as detailed elsewhere, and preferably have a radial slot 37 to decrease losses because of eddy currents as well as to prevent high voltages from being induced into the windings of the toroids. A high voltage may cause a breakdown of the insulation between adjacent layers of the toroid. Radial slot 37 may have a width of 1 mm for example, or as appropriate for each transformer design. The slot 37 is preferably filled with an insulating material, for example a glass-cloth-base laminate.

A cylinder 55 made of an insulating material may be inserted in hole 32, to align together toroids 34 and 35. Another cylinder 55 may be used to align toroids 33 and 34 as shown.
Cylinders 55 may have a central hole, to allow the insertion of a threaded beam (not shown).

Fig. 8 details another embodiment of one column 3 of the three-phase transformer, including longitudinally-oriented ribbon parts 17. The advantage of this structure is that a long column 3 may be achieved without the need to stack parts thereof one on top another.
Thus, column 3 of the magnetic core includes amorphous ribbon parts 17, longitudinally oriented therein. In one embodiment all the ribbons 17 have (not shown) the same width, for example 50 mm.
In another embodiment the ribbons 17 may have various width values. Ribbons of thickness about 25 micron were used, although other thickness values may be used as well.

The cross-sectional shape of column 3 may be rectangular or polyhedral, for example.

An outer cover 36 may be advantageously used for protection. Cover 36 is preferably made of an insulating material, to prevent induction of current therein because of the alternative magnetic flux in the core.

Method of production of magnetic core 3:

1. An amorphous ribbon made of ferromagnetic alloy is cut to pieces, each having the length equal to the height of core 3.
The cutting may be with a +-0.5 mm precision, and the burrs are filed off. The ribbon pieces 17 have a width set according to the required cross-sectional dimensions of core 3.

2. The ribbon pieces 17 are stacked on top of each other in a fixture (not shown), to form a core with the desired dimensions. The fixture includes means to press the pieces 17 together, to achieve the desired coefficient of density, which is about 0.8 to 0.9 .

3. Annealing of the complete core in its fixture, at a temperature of about 350 to 550 degrees Celsius, preferably in a furnace with a controlled atmosphere, for a time period of less than one hour.
Annealing may be performed with or without an external magnetic field being applied to the toroid. A longitudinal or transverse magnetic field may be applied.

4. Impregnation of the toroid with an organic binding material, for example an epoxy resin in a vacuum chamber or in an ultrasonic bath.
Impregnation may be performed with the pieces 17 in the annealing fixture. The core is placed in a thermostat and sintered at a temperature of about 80 - 105 degrees Celsius.

5. The core is removed from the fixture. Excess binding material is removed from the planar surfaces at the top and bottom of the core.

6. To achieve better mechanical strength, the lateral surface of the core is coated with a glass-cloth-base laminate band impregnated with epoxy resin, that is wound about the core. After coating, the band is sintered at a temperature of about 100 to 130 degrees Celsius .

7. For good magnetic properties and to allow for the parts to fit closely to each other during assembly, the upper and lower surfaces of the core may be milled and polished to within 0.1 mm, with the total length of the core set to within a 0.1 mm tolerance. To prevent stratification of the core 3 during machining, it is necessary to chuck the operated zone in a special fixture.

Figs. 9 and 10 illustrate the method of assembly of the transformer: Fig. 9 illustrates one phase of the transformer after mounting the first coil on the core, that is winding 42; Fig. 10 illustrates the transformer with both coils inserted thereon.

The assembly method includes the following steps:

1. Coil 42 of the secondary winding is mounted on core 3 and secured thereon with spacers 56 (see Fig. 9) . The coil 42 is so located as to keep a predefined distance 63 from each of the ends of core 3.

2. Coil 41 of the primary winding is mounted on coil 42 and secured thereon
with spacers 57 (see Fig. 10) . The coil 41 is so located as to keep a predefined distance 64 from each of the ends of core 3.

3. The coils of the other two phases are mounted on cores 3 using a method that is identical to that in steps (1), (2) above.

4. A toroid 2 is set in a horizontal position as illustrated in Fig. 2, with the working surface 26 pointing upwards. A working surface is a planar surface of toroid 2 that was cleaned of excess impregnating material and was optionally polished.

5. A layer of magnetic paste, of thickness about 0.2 mm, is deposited on part 2 in the areas where columns 3 will be mounted.

6. The three cores 3, with coils thereon, are mounted on part 2. The parts are mounted symmetrically about symmetry axis 13.

7. A layer of magnetic paste, of thickness about 0.2 mm, is deposited on the upper area of cores 3.

8. The upper part 1 (toroid) is mounted on the three cores 3, to form the structure as illustrated in Fig. 2 . Thus the complete magnetic core of the transformer is formed.

9. The parts 1, 2 and 3 are secured to each other using three demountable bands 51 with screws 52 to tighten each band.
The structural member 53 made of an insulating material are located between each band 51 and each of the plates 1 and 2. The screws 52 are rotated so as to tighten each band, thus securing the transformer parts together.

To dismantle the transformer, it is only required to rotate screws 52 in the opposite direction. Bands 51 become loose and allow the removal of cores 3 and of parts 1 and 2. Each coil can be then removed from its core, as desired.
The above structure and method allow for multiple cycles of dismantling/assembly of the transformer, without causing damage to the parts of the transformer. This may facilitate the repair of the transformer, and to savings in work and materials.

Fig. 9 details the structure of one column of the three-phase transformer, after mounting the secondary winding 42 on the column 3 of the magnetic core. Core 3 has a radial slot 37 as detailed above.

The spacers 56, made of an insulating material, are used to mechanically attach winding 42 to column 3, while keeping the above parts electrically insulated from each other. The terminals 424 of winding 42 are exposed to allow electrical connections thereto.

The structure is formed while keeping a specific distance 63 between lower end of winding 42 and lower end of column 3. The structure is symmetrical, having the same distance at the upper end of winding 42.

Fig. 10 details the structure of one column of the three-phase transformer, after mounting the primary winding 41 on the column 3 of the magnetic core. Core 3 has a radial slot 37.

The primary winding 41 of the coil block is secured to the secondary winding 42 using spacers 57. Winding 42 is secured to core 3 using spacers 56. Spacers 56 and 57 are made of an insulating material.
The terminals 414 and 424 are used to connect the primary winding 41 and secondary winding 42, respectively, to the electrical source and load.

A mathematical analysis of a transformer made according to the present invention was performed, and results compared to those for a transformer having an E+I core as known in the art.

The evaluation relates to a transformer having rated power values of 10 kVA , 25 kVA, 100 kVA and 630 kVA. The analysis included computation of the electrical core and winding losses, weight and cost of materials.
All calculations were performed for a fixed, predefined value of overall efficiency. The results are detailed in the following tables.

Parameters common to all the tables:

1. f= 50 Hz ; f – frequency, Hz
2. Three phase transformer
3. Cuw= 5$/kg ; Cuw – price of winding materials, $/kg
4. Cufe= 3.0 $/kg ; Cufe – price of amorphous material, $/kg
5. C'ufe= 1.5 $/kg ; C'ufe – price of silicon steel, $/kg

Variables in the tables:

Pw – core loss, W
Pfe – winding loss, W
Gw – winding weight, kg
Gfe – core weight, kg
Gtr – total transformer weight, kg
η – efficiency, %
Cw – cost of winding materials, $
Cfe – cost of magnetic core, $
Ctr – total cost of transformer materials, $
Htr – transformer height, mm (millimeters)
Ltr – transformer length, mm
Btr – transformer width, mm
Vtr – transformer volume, m^3
P2 – output power, kVA
U1 – primary voltage, V
U2 – secondary voltage, V

Table 1

P2= 10 kVA ; U2= 220 V ; U1= 380 V

Type of transformer	Core design	Core material	Pw, W	Pfe, W	Gw, KG	Gfe, KG	Gtr, KG
AMT, dry Israel	Toroid	Amorphous metal	330	12	26	58	85
TSZM-10/0.4	E+1 type	Silicon steel	256	78	59	40	99

Table 1 (cont.)

Type of transformer	η, %	Cw, $	Cfe, $	Ctr, $	Htr, mm	Ltr, mm	Btr, mm	Vtr, m^3
AMT, dry Israel	96.7	130	174	304	214	349	349	0.026
TSZM-10/0.4	96.7	295	60	355	465	600	335	0.093

Table 2

P2= 25 kVA ; U2= 220 V ; U1= 380 V

Type of transformer	Core design	Core material	Pw, W	Pfe, W	Gw, KG	Gfe, KG	Gtr, KG
AMT, dry Israel	Toroid	Amorphous metal	697	19.3	64.5	95.5	160
TSZM-25/0.4	E+1 type	Silicon steel	558	157	133	77	200

Table 2 (cont.)

Type of transformer	η, %	Cw, $	Cfe, $	Ctr, $	Htr, mm	Ltr, mm	Btr, mm	Vtr, m^3
AMT, dry Israel	97.2	322	287	609	242	441	441	0.47
TSZM-25/0.4	97.2	665	116	781	555	706	463	0.18

Table 3

P2= 100 kVA ; U2= 380 V ; U1= 22.5 kV

Type of transformer	Core design	Core material	Pw, W	Pfe, W	Gw, KG	Gfe, KG	Gtr, KG
AMT, dry Israel	Toroid	Amorphous metal	2040	48	132	238	371
Siblok, dry	E+1 type	Silicon steel	1700	440	160	405	565

Table 3 (cont.)

Type of transformer	η, %	Cw, $	Cfe, $	Ctr, $	Htr, mm	Ltr, mm	Btr, mm	Vtr, m^3
AMT, dry Israel	97.9	660	714	1474	706	1270	1270	1.13
Siblok, dry	97.9	800	607	1407	1180	1300	925	1.41

Table 4

P2= 630 kVA ; U2= 380 V ; U1= 22.5 kV

Type of transformer	Core design	Core material	Pw, W	Pfe, W	Gw, KG	Gfe, KG	Gtr, KG
AMT, dry Israel	Toroid	Amorphous metal	7071	136	650	683	1333
Siblok, dry	E+1 type	Silicon steel	5600	1600	570	1740	2310

Table 4 (cont.)

Type of transformer	η, %	Cw, $	Cfe, $	Ctr, $	Htr, mm	Ltr, mm	Btr, mm	Vtr, m^3
AMT, dry Israel	98.87	3249	2049	5298	866	766	766	0.5
Siblok, dry	98.87	2850	2610	5460	1850	1820	1186	4

Table 5

P2= 630 kVA ; U2= 380 V ; U1= 22.5 kV

Type of transformer	Core design	Core material	Pw, W	Pfe, W	Gw, KG	Gfe, KG	Gtr, KG
AMT, dry Israel	Toroid	Amorphous metal	5880	148	537	739	1276
Allied Signal, Oil, USA	E+1 type	Silicon steel	5835	186	487	932	1419

Table 5 (cont.)

Type of transformer	η, %	Cw, $	Cfe, $	Ctr, $	Oil	Tank
AMT, dry, Israel	99.05	2686	2217	4902	–	–
Allied Signal, Oil, USA	99.05	2435	2796	5231	+	+

The computations for the transformers having various power ratings and voltage levels indicate an advantage for the transformer made according to the present invention, including among others:

1. A decrease of total weight by about 14% to 43%
2. A decrease in cost by about 3% – 22%
3. A decrease in transformer volume by about 20% to 87%

A prototype of the transformer according to the present invention was build, having the following parameters:

P2= 1 kVA ; U1= 380 V ; U2= 220 V; f= 50 Hz ;η = 92.66% ; Gtr= 16.4 kg

The transformer was found to have good maintainability, its easy dismantling and reassembly being facilitated by its modular structure as detailed above.

A similar transformer, having a structure as known in the art, has an efficiency of η = 91% and weight Gtr= 20 kg. Thus, the new structure may achieve a decrease in transformer weight of 18% at a higher efficiency.

It will be recognized that the foregoing is but one example of an apparatus and method within the scope of the present invention and that various modifications will occur to those skilled in the art upon reading the disclosure set forth hereinbefore.

CLAIMS

What is claimed is:

1. A three-phase transformer comprising three coil blocks and a magnetic core, wherein the magnetic core includes a core column for each phase together with a lower plate and an upper plate to transfer magnetic flux between said columns, with one of said coil blocks mounted on each of said columns, and wherein said columns and plates are made of ribbons of a ferromagnetic amorphous alloy.

2. The three-phase transformer according to claim 1, wherein each of said coil blocks includes a primary and a secondary coil for one of said three phases of the transformer.

3. The three-phase transformer according to claim 1 or 2, wherein said magnetic core includes an upper plate, a lower plate and three identical columns, assembled together so that said plates are parallel to each other, with said columns mounted as supports between the plates so as to form a cage-like structure having a spatial symmetry about a central axis.

4. The three-phase transformer according to claim 1 or 2, wherein each of said upper and lower plates is made of a ribbon wound into a toroidal shape.

5. The three-phase transformer according to claim 1 or 2, wherein each of said columns is made of a ribbon wound into a toroidal shape.

6. The three-phase transformer according to claim 1 or 4, wherein each of said upper and lower plates is made of an amorphous ribbon wound into a generally triangular shape with rounded corners.

7. The three-phase transformer according to claim 1 or 4, wherein each of said upper and lower plates is made of an amorphous ribbon wound into a generally circular shape.

8. The three-phase transformer according to claim 1 or 5, wherein each of said magnetic core columns comprises a plurality of core elements stacked on top each other, to achieve a magnetic core column of increased height.

9. The three-phase transformer according to claim 1 or 2, wherein said columns, plates and coil blocks are assembled together using attaching means with means for allowing multiple cycles of assembly and dismantling of said transformer.

10. The three-phase transformer according to claim 4 or 5, wherein said plates and/or said columns have a radial slot cut therein.

11. The three-phase transformer according to claim 10, wherein each of said slots is filled with an isolating material.

12. The three-phase transformer according to claim 1 or 2, wherein each of said columns is made of ribbon pieces attached to each other, with each ribbon piece being in a planar state and oriented along the magnetic core.

13. The three-phase transformer according to claim 1 or 2, wherein each of said plates has dimensions so as to contact the whole area of the upper and lower surfaces of said columns, when said columns are located in their position according to the diameter of said coil blocks.

14. The three-phase transformer according to claim 1 or 2, further including a fourth column parallel to said three columns, to provide a return path for the magnetic flux between said plates.

15. The three-phase transformer according to claim 9, wherein said attaching means include three screws passing each through a central longitudinal hole in one of said columns and corresponding holes in said upper and lower plates.

16. The three-phase transformer according to claim 9, wherein said attaching means include three screws passing each through a central longitudinal hole

17. The three-phase transformer according to claim 9, wherein said attaching means include demountable bands which are tightened with screws, together with a structural member that is located between each band and one of the adjacent upper or lower plates.

18. The three-phase transformer according to claim 9, wherein said attaching means include three threaded beams or screws with corresponding nuts, together with structural members that are attached to each of the upper and lower plates, with each of said structural members including means adapted for the thread and nut structure.

19. The three-phase transformer according to claim 1 or 2, wherein gaps between said plates and columns of the magnetic core are filled with a magnetic paste.

20. The three-phase transformer according to claim 8, wherein gaps between said core elements comprising each column are filled with a magnetic paste.

21. The three-phase transformer according to claim 19 or 20, wherein the magnetic paste filling said gaps is made of an amorphous powder with soft ferromagnetic properties, having particle size larger than about 20 micron, and a binding insulating material like transformer oil or epoxy resin.

22. The three-phase transformer according to claim 21, wherein the concentration of amorphous powder in said magnetic paste is between about 50% and 90% .

23. The three-phase transformer according to claim 1 or 2, wherein said plates are each made of a toroid of an amorphous ribbon of about 20 mm width and 25 micron thickness.

24. The three-phase transformer according to claim 1 or 2, wherein said columns are each made of a toroid of an amorphous ribbon of about 20 mm width and 25 micron thickness.

25. The three-phase transformer according to claim 8, wherein said core elements are each made of a ribbon about 10 to 100 mm wide.

26. A method of manufacture of a three-phase transformer comprising the steps of:

A. Production of amorphous ribbons of an alloy having soft ferromagnetic properties;

B. Production of magnetic core elements from said amorphous ribbons, including three columns and two plates;

C. Production of coil block 4 assemblies, with each block including a primary and secondary winding;

D. Impregnation and/or coating of the core elements and/or windings;

E. Assembly of the transformer, including the steps of insert a core into each coil block, securing coils in position, mounting three columns each in a corner of the lower base plate, placing the upper base plate on the three columns and securing all the parts together.

27. The method of manufacture of a three-phase transformer according to claim 26, wherein in step (B) the core elements are toroids made of said amorphous ribbon.

28. The method of manufacture of a three-phase transformer according to claim 26, wherein in step (B) each of said columns is made of ribbon pieces attached to each other, with each ribbon piece being in a planar state and oriented along the magnetic core.

29. The method of manufacture of a three-phase transformer according to claim 26, wherein in step (B) a plurality of toroids are made to form each of said columns when said toroids are stacked on top each other.

30. The method of manufacture of a three-phase transformer according to claim 26, wherein in step (C) each winding is separately produced and assembled as a separate unit.

31. The method of manufacture of a three-phase transformer according to claim 27, wherein in step (B) each said toroid is manufactured using a method comprising the following steps:

F. Coating an as-cast amorphous alloy ribbon with an insulating layer;

G. Winding of a toroid from the as-cast ribbon;

H. Securing the last layer of the toroid to the previous layer;

I. Annealing of the complete toroid at a temperature of about 350 to 550 degrees Celsius;

J. Impregnation of the toroid with an organic binding material; and

K. Removal of excess impregnation material removed from the planar surfaces of the toroid that come into contact with other magnetic core parts.

32. The method of manufacture of a three-phase transformer according to claim 31, further including the step of polishing of working surfaces of the toroids.

33. The method of manufacture of a three-phase transformer according to claim 31, further including the step of coating the lateral circular area of the toroid with a glass-cloth-base laminate band that is wound about the toroid and is sintered at a temperature of about 100 to 130 degrees Celsius.

34. A three-phase transformer of the kind specified substantially as herein before described by way of example with reference to the accompanying drawings.

Mark Zuta, Patent Attorney

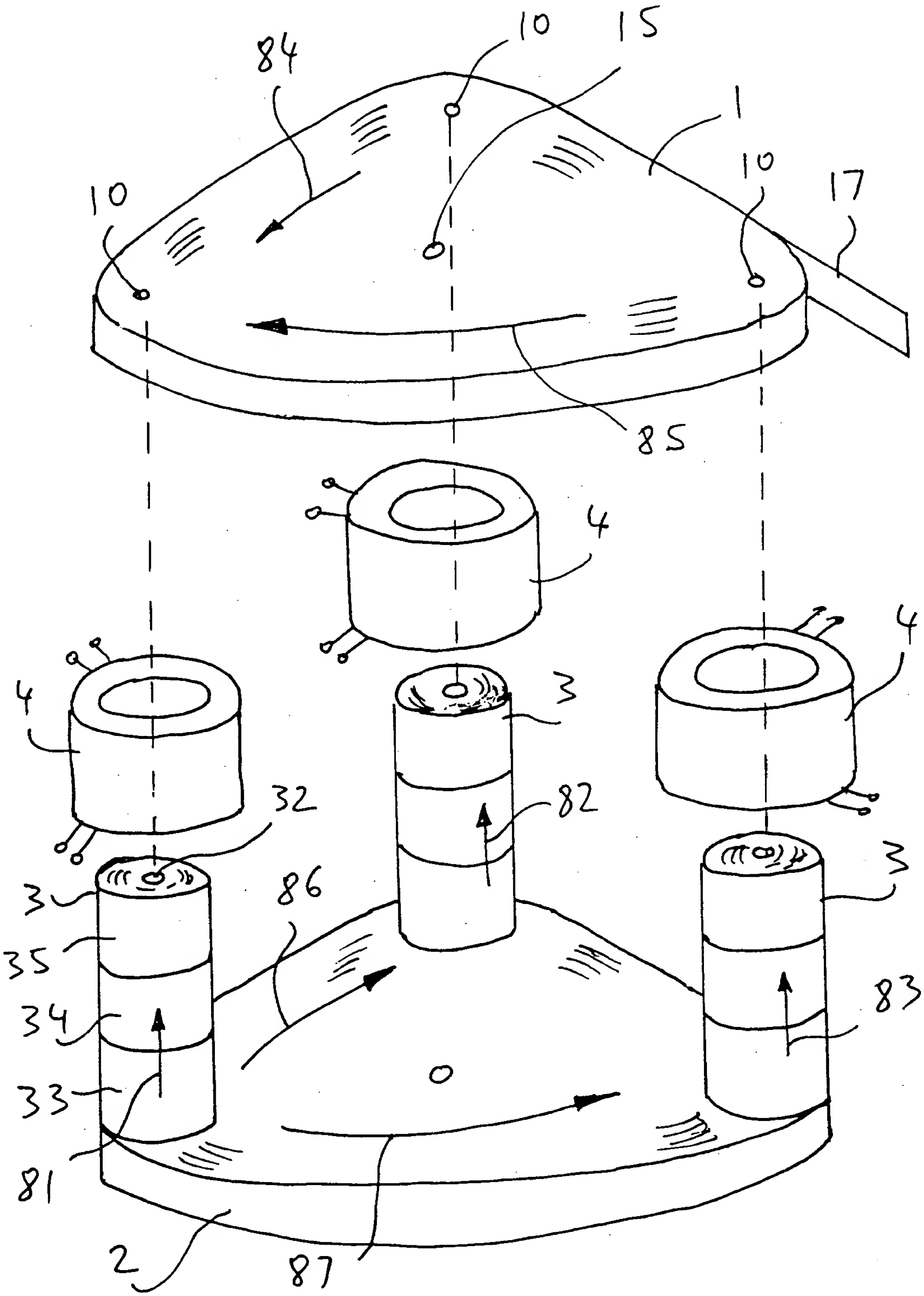

Fig. 1

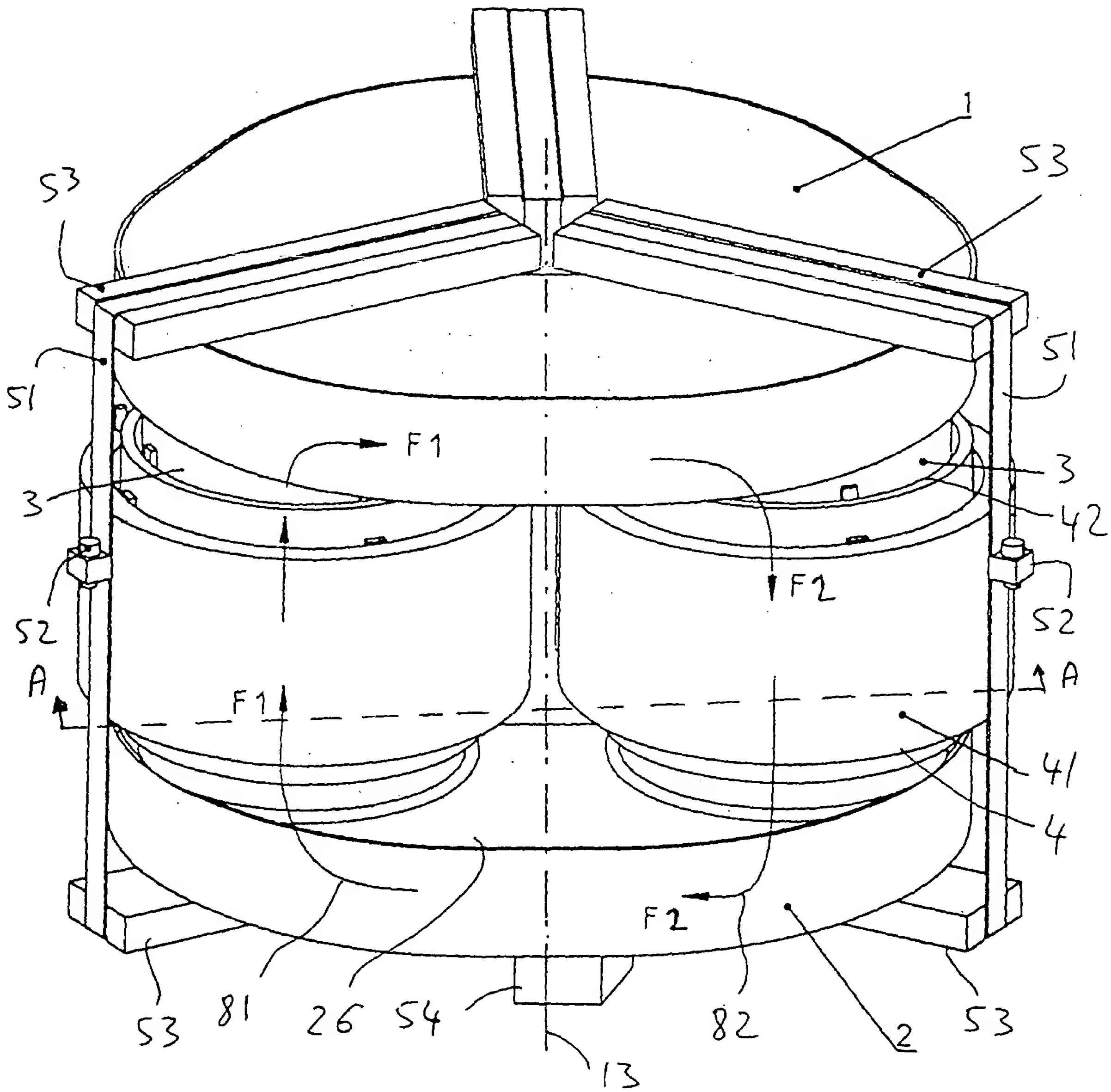

Fig. 2

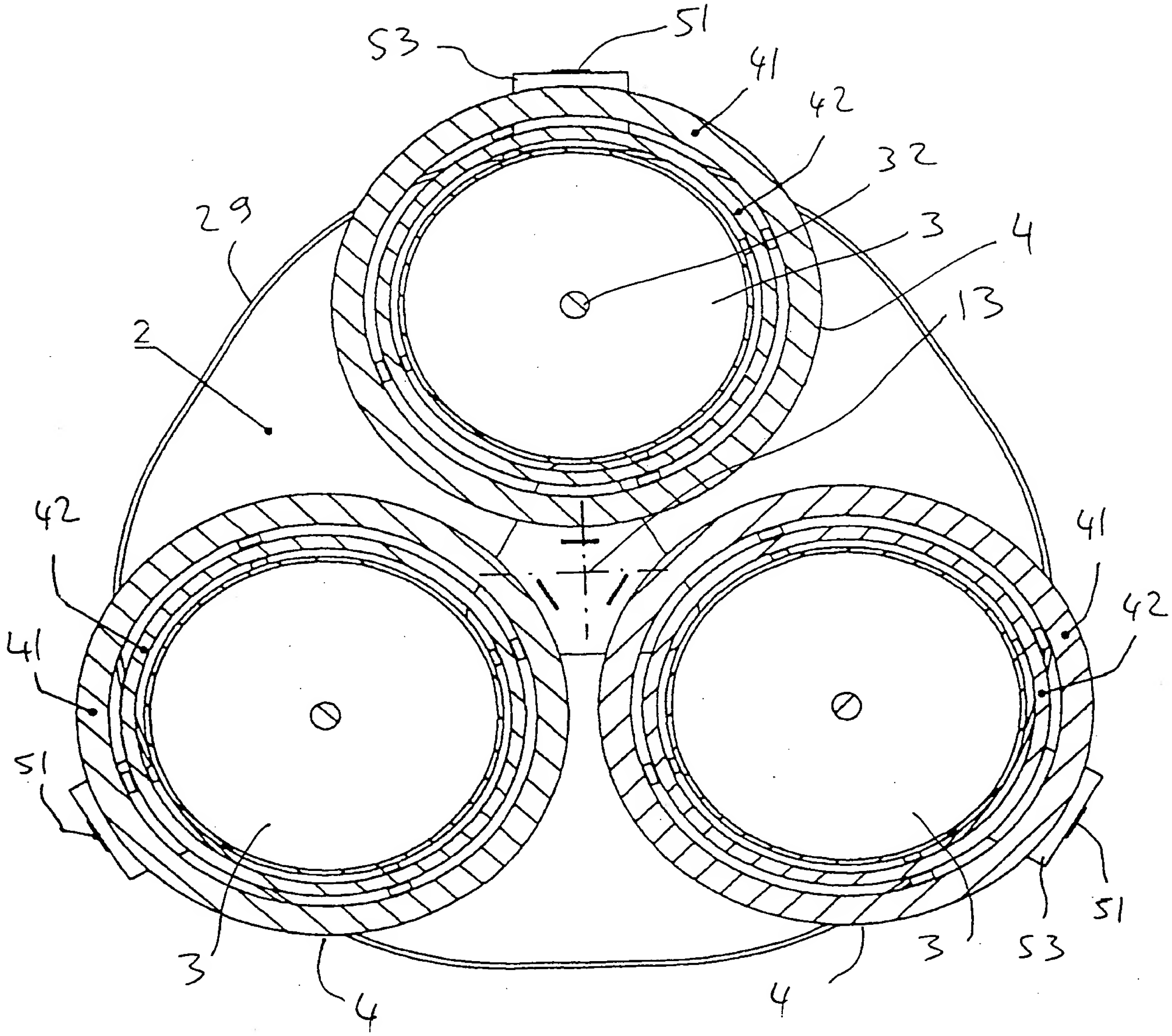

Fig. 3

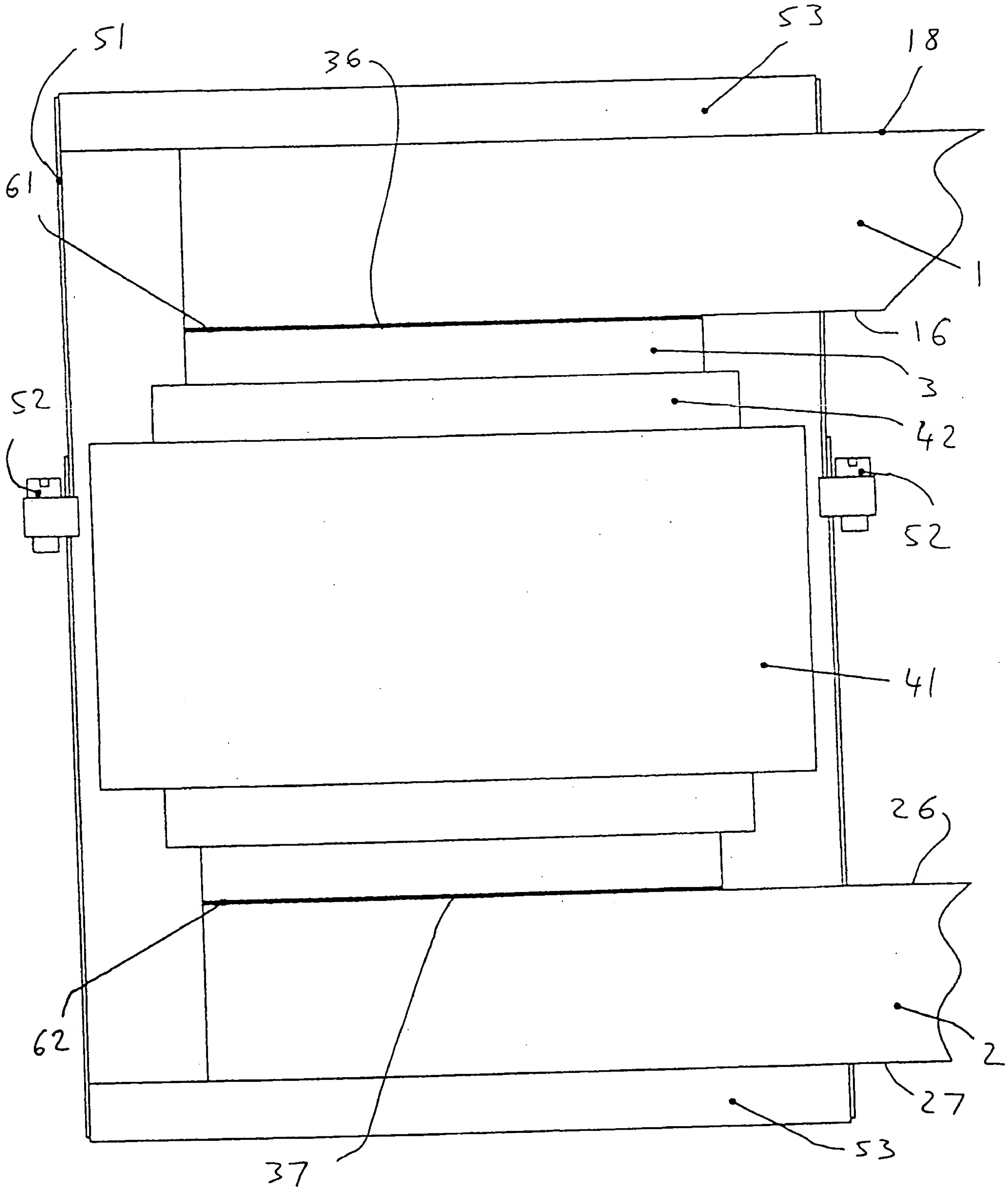

Fig. 4

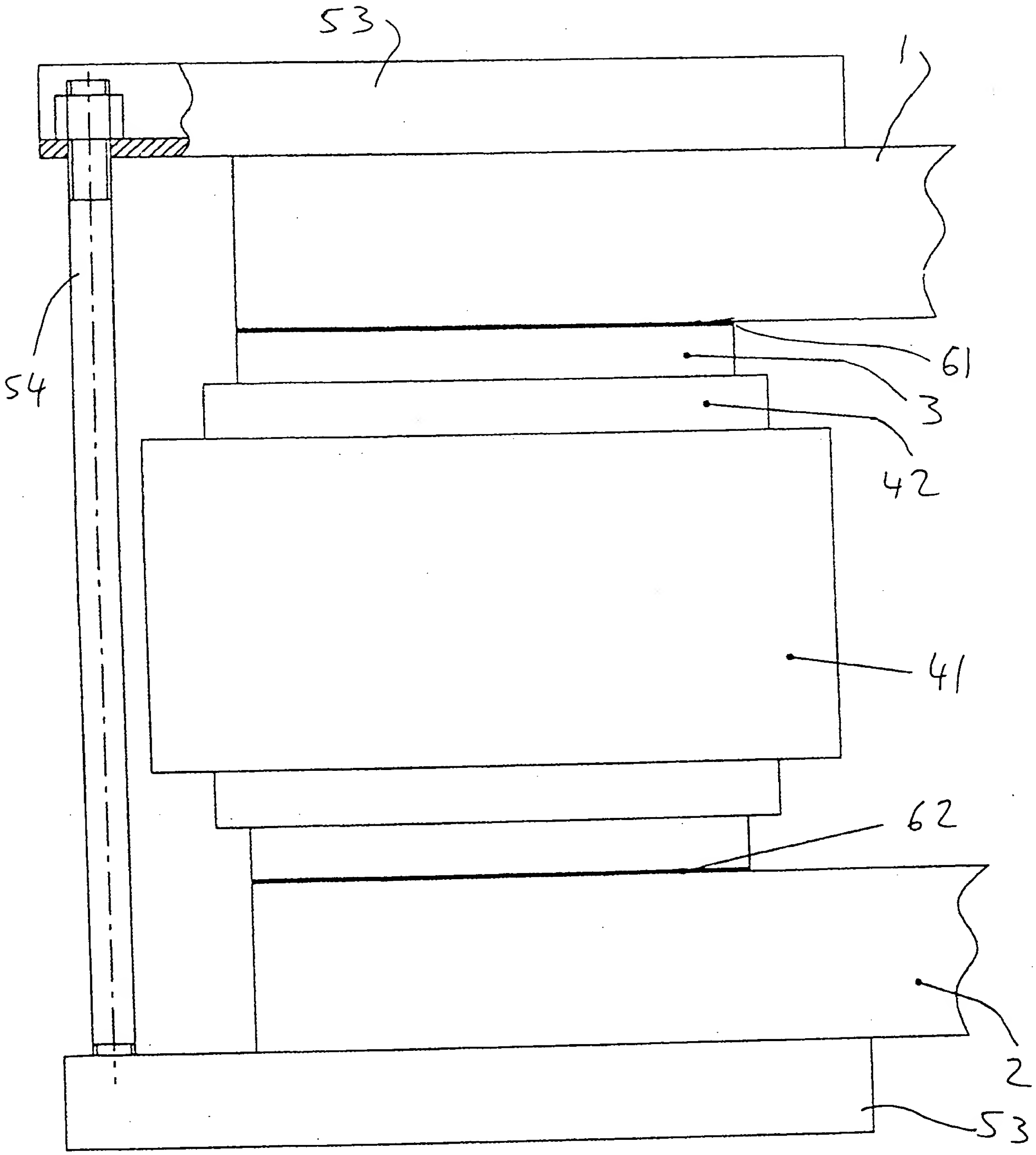

Fig. 5

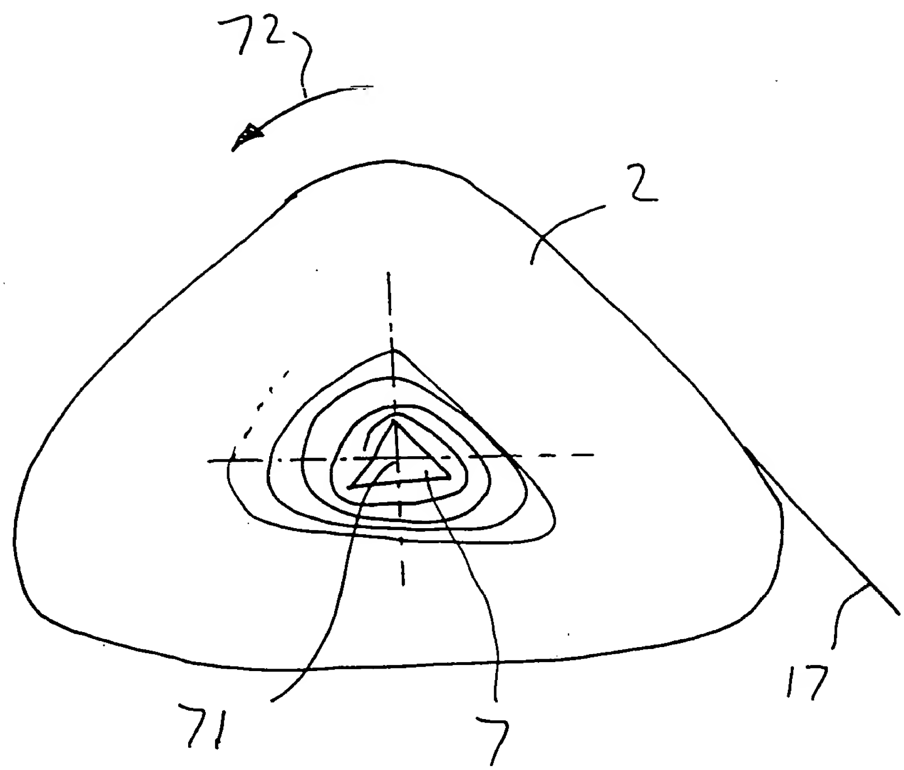

Fig. 6

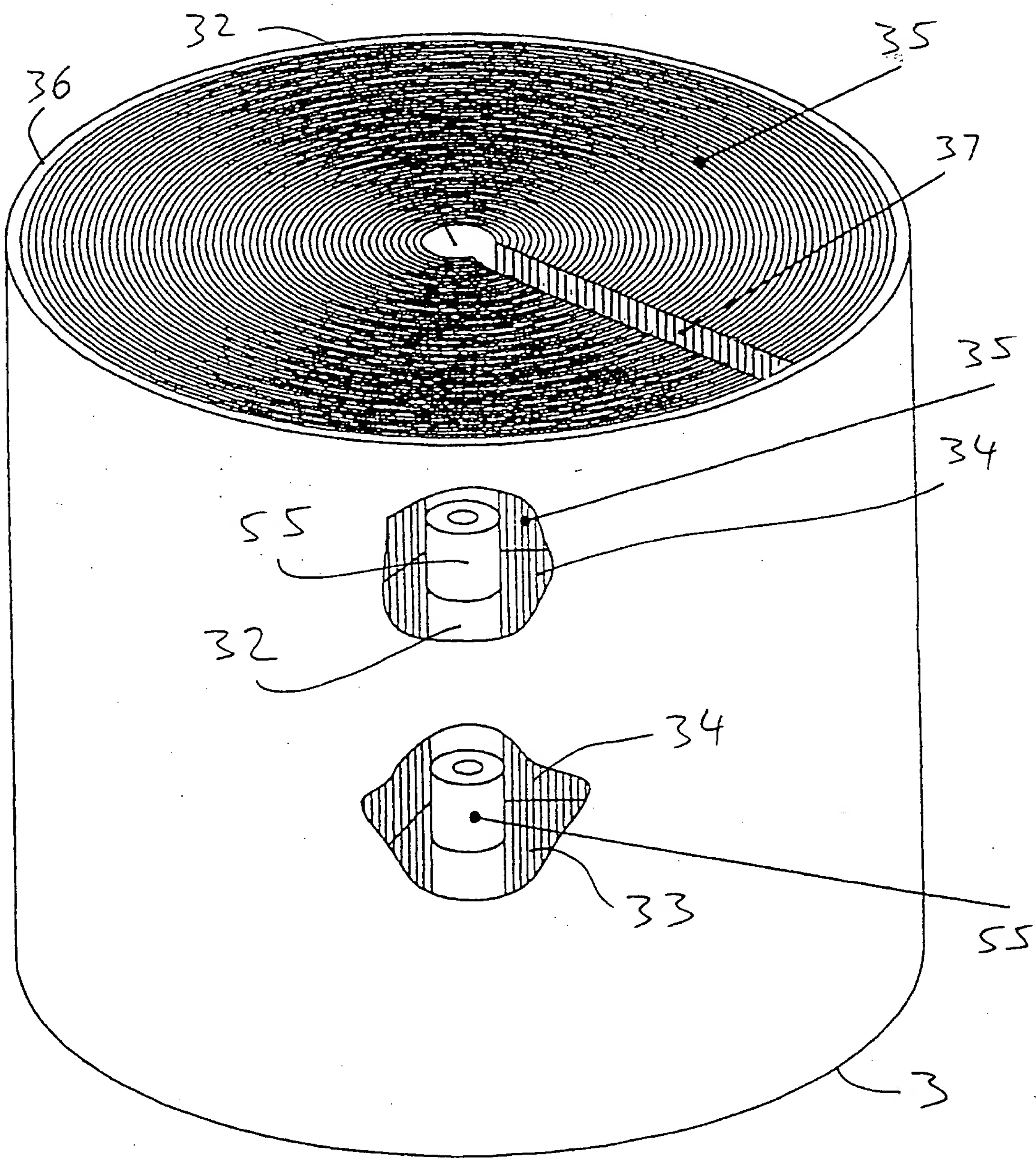

Fig. 7

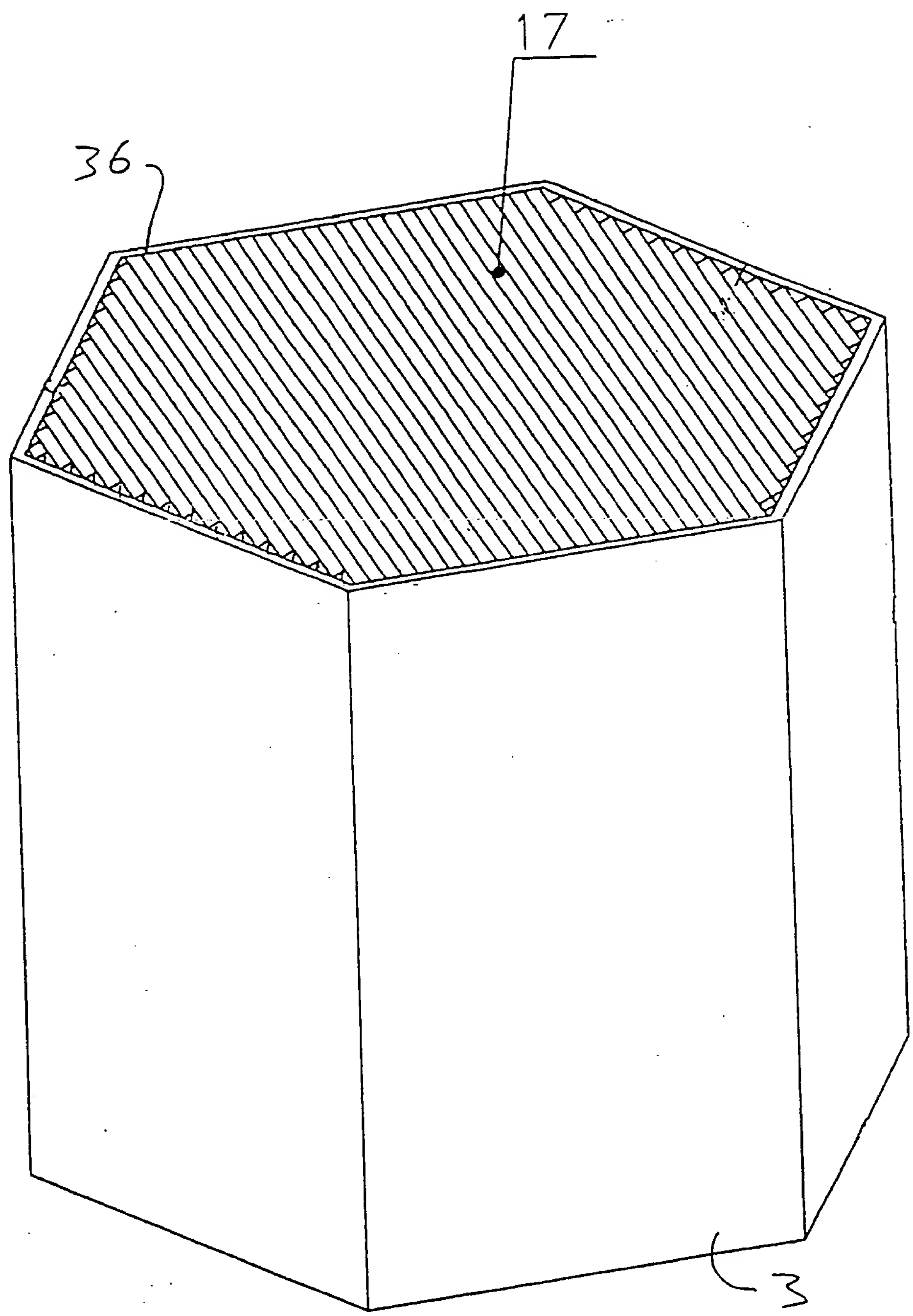

Fig. 8

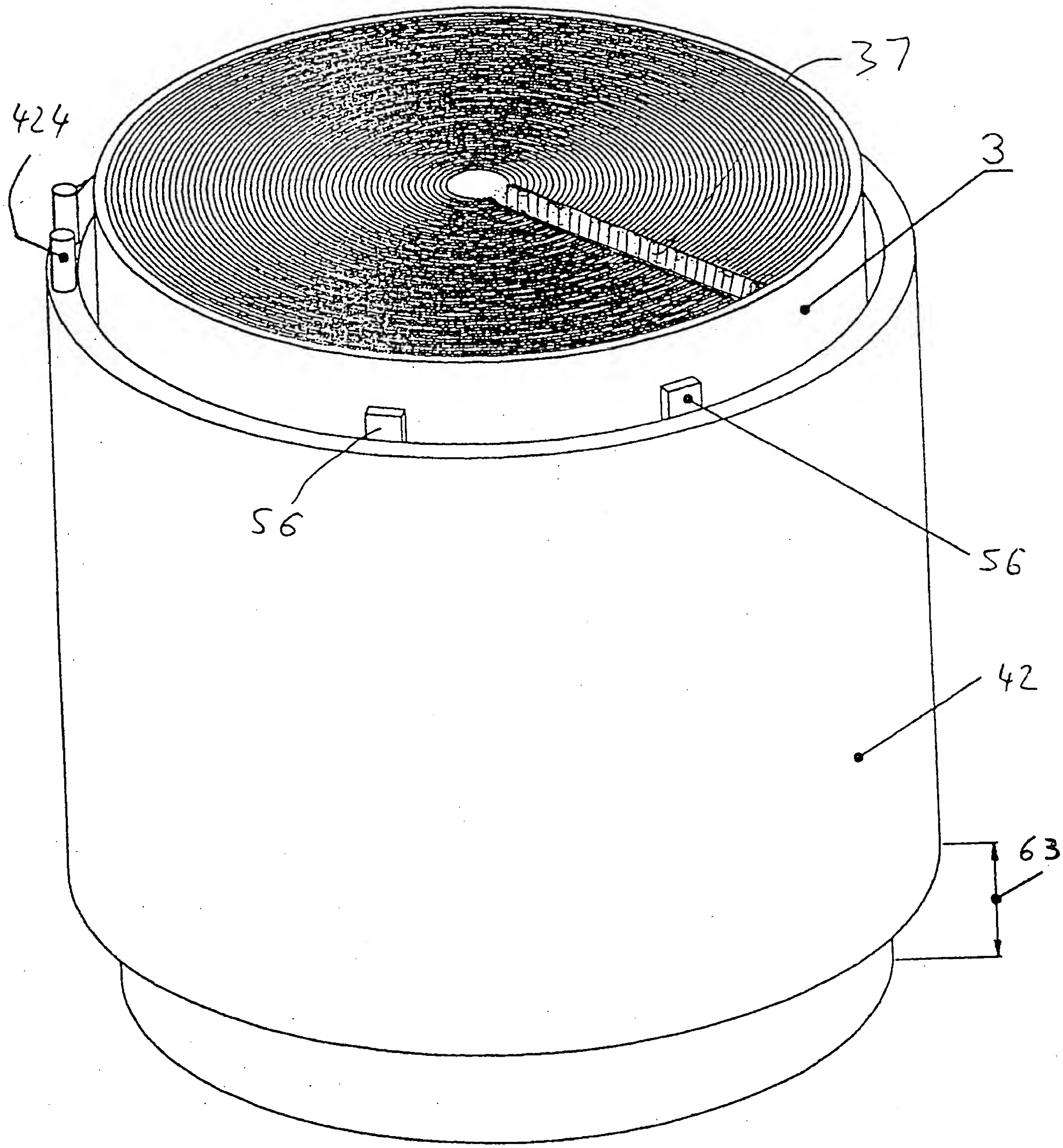

Fig. 9

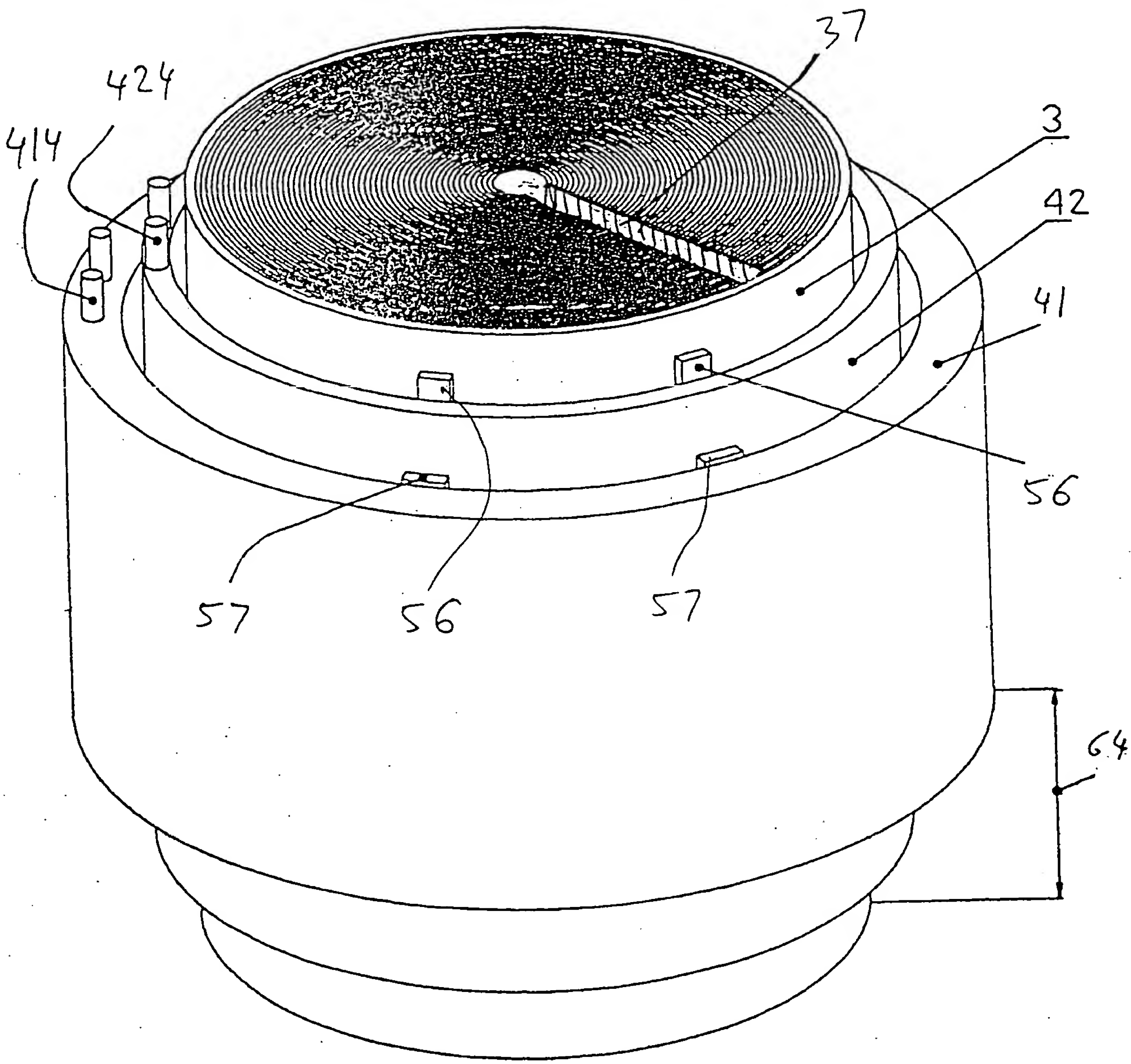

Fig. 10